FORM PTO-1390 U.S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE
(REV. 10-96)

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

Rec'd PCT/PTO 19 MAR 2002

		ATTORNEY DOCKET NUMBER MA/JM
		U S APPLICATION NO. (If known, sect 37 C.F.R 1.5) Not Yet Known 10/088592
INTERNATIONAL APPLICATION NO. PCT/AU00/01151	INTERNATIONAL FILING DATE 21 September 2000	PRIORITY DATE CLAIMED 21 September 1999

TITLE OF INVENTION

A GRATING DESIGN

10/088592

APPLICANT(S) FOR DO/EO/US

Dmitrii Yu STEPANOV and Mark SCEATS

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau. **(see enclosed Form PCT/IB/308)**
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☐ Other items or information.

...LICATION NO. (If known, see 37 C F R 1.53)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
Not Yet Known 09/088372	PCT/AU00/01151	A-71409/RMA/JML

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

	CALCULATIONS	(PTO USE ONLY)
Search Report has been prepared by the EPO or JPO $890.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) $710.00		
No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $740.00		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO $1,040.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 1,040.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE		
Total Claims	8	-20 =	0	$ 18.00	$ -0-	
Independent Claims	7	-3 =	4	$ 84.00	$ 336.00	
Multiple dependent claims (if applicable)			n/a	$280.00	$ -0-	

TOTAL OF ABOVE CALCULATIONS =	$ 1,506.00	
Reduction by 1/2 for filing by small entity, if applicable. Applicant claims small entity status. (See 37 CFR 1.27.) Yes: ☐ No: ✔	$ -0-	
SUBTOTAL =	$ 1,506.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$ -0-	
TOTAL NATIONAL FEE =	$ 1,506.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +	$ -0-	
TOTAL FEES ENCLOSED =	$ 1,506.00	
	Amount to be: refunded	$
	charged	$

☒ A check in the amount of $1,506.00 to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. 06-1300 (Order No. ______) in the amount of $ ______ to cover the above fees.

☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 06-1300 (Order No. A-70419/RMA/JML).

NOTE: **Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.**

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35,050
REGISTRATION NUMBER

10088549 Received 23 October 2001
CORRECTED VERSION

ART 34 AMDT

A grating design

Field of the invention

The present invention relates broadly to a grating structure, method of writing the grating structure and devices incorporating such gratings. The present invention will be described herein with reference to grating structures for non-linear group delay dispersion compensation. However, it will be appreciated that the invention does have broader applications, such as for engineering of phase response of a fibre Bragg grating device.

Background of the invention

Grating structures are widely used in optical waveguides for example as filters or as compensators for linear group delay dispersion.

In many systems non-linear group delay dispersion, i.e. second and higher order group delay dispersion, plays a significant role. Therefore, it is desirable that a compensator structure be provided that can compensate for non-linear group delay dispersion in such systems.

Summary of the invention

The present invention provides an optical device incorporating a sampled grating structure having a chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

The optical waveguide may be in the form of an optical fibre.

Alternatively, the optical waveguide may be in the form of a planar waveguide.

The present invention may alternatively be defined as a method of producing a grating structure in a photosensitive optical waveguide, the method comprising the step of irradiating the device with UV light at an intensity sufficient to induce refractive index variations in the waveguide in a manner to produce a sampled grating structure, wherein the radiation is controlled in a manner to effect chirping of the sampling period, and such that a dispersion characteristic of the grating structure is substantially proportional to the inverse on a non-linear dispersion function over a selected wavelength range.

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The method may further comprise a step of applying an apodisation function during the UV-inducing of the refractive index variations to produce a smooth grating profile. This can help to avoid ripples.

The photosensitive optical waveguide may comprise an optical fibre or planar optical waveguide.

The invention further provides an optical waveguide incorporating a sampled grating structure a having chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

The invention may alternatively be defined as a method of compensating for non-linear group delay dispersion in an optical signal, comprising transmitting the optical signal through a sampled grating structure having a chirped sampling period.

The invention may alternatively be defined as providing a group delay dispersion compensator device comprising a sampled grating structure a having chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

Having made this invention, it has been recognised that a method of producing a zero dispersion WDM channel can be provided, the method comprising the steps of:

- filtering a narrow band optical signal from an input broad band optical signal using a square reflection band filter;

- using a sampled grating structure having a chirped sampling period to compensate for dispersion of the narrow band optical signal in the reflection band filter.

It is noted here that the terms “narrow band” and “broad band” are not intended to be limited to a particular range, but rather to indicate the relative breadth of one when compared with the other.

Further, the present invention provides a device for producing a zero dispersion WDM channel, the device

comprising a square reflection band filter for filtering a narrow band optical signal from an input broad band optical signal, and following the optical filter, a sampled grating structure having a chirped sampling period for compensating for dispersion of the narrow band optical signal in the square reflection band filter.

The device may comprise a circulator having a plurality of ports, the square reflection band filter being located at one of the ports for filtering the square amplitude narrow band optical signal from the input broad band optical signal entering the circulator at an input port, and the sampled grating structure being located at another port of the circulator to compensate for dispersion in the square band filter, the circulator further comprising an output port for outputting the dispersion-compensated narrow band optical signal.

The invention has applications for both planar and cylindrical waveguides such as optical fibres.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Brief Description of the Drawings

Figure 1A shows a typical refractive index profile of a grating produced by UV-induced refractive index variations.

Figure 1B shows a portion of the profile shown in Fig. 1A on an expanded length scale to more clearly show the refractive index variations in the grating.

Figure 2 is a schematic drawing illustrating direct UV writing techniques.

Figure 3 is a schematic drawing illustrating interferometric UV writing techniques.

Figure 4A shows a refractive index profile of a sampled grating.

Figure 4B shows a portion of the profile shown in Fig. 4A on an expanded length scale to more clearly show the refractive index variations in the grating.

Figure 5A shows a refractive index profile of a grating embodying the present invention.

Figure 5B shows a portion of the profile shown in Fig. 5A on an expanded length scale to more clearly show the refractive index variations in the grating.

Figure 6 is a plot illustrating group delay dispersion of an apodised grating embodying the present invention.

Figure 7A shows an apodised refractive index profile of a grating embodying the present invention.

Figure 7B shows a portion of the profile shown in Fig. 7A on an expanded length scale to more clearly show the refractive index variations in the grating.

Figure 8 shows a plot illustrating group delay dispersion of a WDM channel.

Figure 9 is a schematic drawing of an optical device embodying the present invention.

Figure 10 shows a plot illustrating the resulting group delay dispersion of the optical device of Figure 9.

Detailed Description of the Preferred Embodiments

In Figures 1A and 1B, a typical refractive index profile 10 of a grating produced by UV-induced refractive index variations in a photosensitive waveguide material is shown. The profile is substantially sinusoidal, with a spatial period Λ. For Bragg gratings, typical spatial periods will be of the order of parts of micrometers such that the Bragg condition is fulfilled for a particular wavelength. Typically, the wavelengths of optical signals utilised in optical devices are between 1200 and 1600 nm.

The refractive index profile 10 is achieved by utilising interference of UV light beams for UV-inducing the refractive index variations in a photosensitive

material, either through direct writing techniques (see Figure 2) or interferometric techniques (see Figure 3).

In sampled gratings the amplitude of the refractive index variation (e.g. sinusoidal variation) is varied periodically, resulting in a refractive index profile 40 as illustrated in Figures 4A and 4B. A typical sampling period length would be of the order of millimeters.

From the above it follows that whilst the spatial period of the grating, which is typically of the order of parts of micrometers, is a parameter which is experimentally difficult to control and/or manipulate, the sampling spatial period is experimentally relatively easy to control and/or manipulate.

As illustrated in Figures 5A and 5B, the refractive index profile 50 of a sampled grating for which the sampling period has been chirped, the spatial period of the sinusoidal "envelope" 52 due to the sampling function decreases along the length of the grating. Importantly, the period of the grating Λ_2 remains constant throughout the entire length of the grating, thereby placing no special demands on the writing of the short period structure. Only the relatively "long" period of the sampling function needs to be varied.

It is noted here that for illustrative purposes the sampling period lengths of Figures 5A and 5B have been set to higher values as they would typically be in a real system.

In Figure 6, the group delay dispersion 60 of an example sampled grating written with a chirped sampling period is shown. The sampling function is:

$$\left\{\cos\left[(K_0+\Delta K(z))z\right]+\cos\left[(K_0-\Delta K(z))z\right]\right\}/2=\cos\left[K_0 z\right]\cos\left[\Delta K(z)z\right].$$

Furthermore, an apodisation function has been applied in the form of a function which monotonically decreases from a starting value at the beginning of the grating to zero at the end of the grating. The refractive index

profile 62 of the resulting grating is shown in Figures 7A and 7B.

It will be appreciated that the group delay dispersion shown in Figure 6 can be utilised to compensate for non-linear group delay dispersion, for example for non-linear group delay dispersion in a WDM channel.

In Figure 8, the group delay dispersion 80 of a WDM channel is illustrated. The group delay dispersion is substantially inverse to the group delay dispersion 60 of the example grating structure (see Figure 6) and it will be appreciated by a person skilled in the art that through appropriate selection of the sampling function and apodisation function, group delay dispersion in WDM channels can be compensated using a sampled grating for which the sampling period has been chirped.

In Figure 9, an optical device 90 comprises a circulator 92 having a sampled grating structure 91 with a chirped sampling period at one port 94 and a grating filter 96 optimised for "square" reflection band amplitude response at another port 98. An incoming broad band optical signal 100 entering the circulator at an input port 102 will initially propagate to the grating filter 96, of which a narrow band signal (not shown) within the square reflection band is reflected back into the circulator 92. The narrow band signal is then reflected at the sampled grating 91 having the chirped sampling period, whereby an output signal 106 leaving the circulator 92 at an output port 108 will be a narrow band optical signal with substantially zero group delay dispersion within the square-shaped amplitude "channel". In other words, the group delay is substantially constant within the square-shaped amplitude channel, as shown in Figure 10, portion 110 of graph 112.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific

embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

For example, apodisation functions other than the one described could be used during the writing of the sampled grating with a chirped sampling period.

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Claims

1. An optical device incorporating a sampled grating structure having a chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

2. An optical waveguide incorporating a sampled grating structure having a chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

3. A group delay dispersion compensator device comprising a sampled grating structure having a chirped sampling period, wherein the grating structure is arranged in a manner such that, in use, a dispersion characteristic of the grating structure is substantially proportional to the inverse of a non-linear dispersion function over a selected wavelength range.

4. A device for producing a zero dispersion WDM channel, the device comprising a square reflection band filter for filtering a narrow band optical signal from an input broad band optical signal, and following the optical filter, a sampled grating structure having a chirped sampling period for compensating for dispersion of the narrow band optical signal in the square reflection band filter.

5. A device in accordance with claim 4, comprising a circulator having a plurality of ports, the square reflection band filter being located at one of the ports for filtering the square amplitude narrow band optical signal from the input broad band optical signal entering the circulator at an input port, and the sampled grating structure being located at another port of the circulator to compensate for dispersion in the square band filter, the circulator further comprising an output port for outputting the dispersion-compensated narrow band optical signal.

6. A method of producing a grating structure in a photosensitive optical waveguide, the method comprising the step of irradiating the device with UV light at an intensity sufficient to induce refractive index variations in the waveguide in a manner to produce a sampled grating structure, wherein the radiation is controlled in a manner to effect chirping of the sampling period, and such that a dispersion characteristic of the grating structure is substantially proportional to the inverse on a non-linear dispersion function over a selected wavelength range.

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7. A method of compensating for non-linear group delay dispersion in an optical signal, comprising utilising a sampled grating structure having a chirped sampling period.

8. A method of producing a zero dispersion WDM channel, the method comprising:

- filtering a narrow band optical signal from an input broad band optical signal using a square reflection band filter;

- using a sampled grating structure having a chirped sampling period to compensate for dispersion of the narrow band optical signal in the reflection band filter.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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PCT

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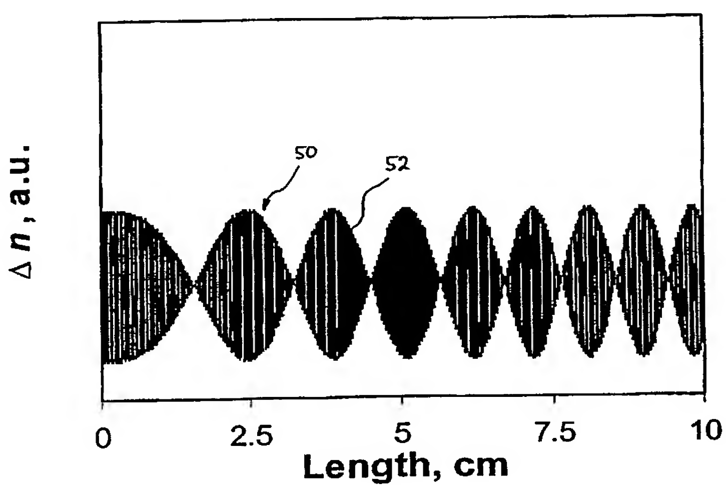
(81) Designated States (*national*): AU, CA, JP, KR, US.

(84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *With international search report.*

(54) Title: A GRATING DESIGN



(57) Abstract: The present invention provides an optical device incorporating a sampled grating structure having a chirped sampling period. The present invention may alternatively be defined as a method of producing a grating structure in a photosensitive optical waveguide, the method comprising the step of irradiating the device with UV light at an intensity sufficient to induce refractive index variations in the waveguide in a manner to produce a sampled grating structure, and wherein the radiation is controlled in a manner to effect chirping of the sampling period. The invention may alternatively be defined as providing a group delay dispersion compensator device comprising a sampled grating structure a having chirped sampling period. It has also been recognised that a method of producing a zero dispersion WDM channel can be provided.

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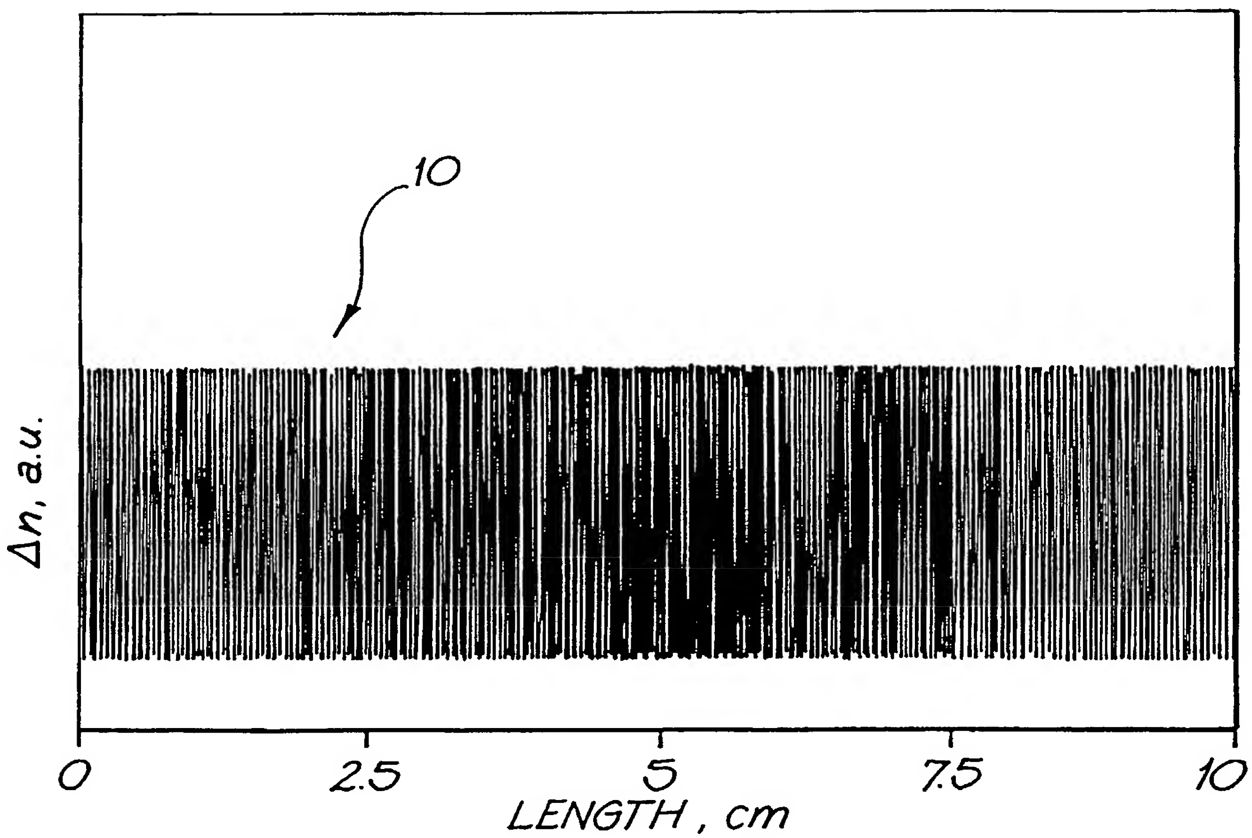


FIG. 1A

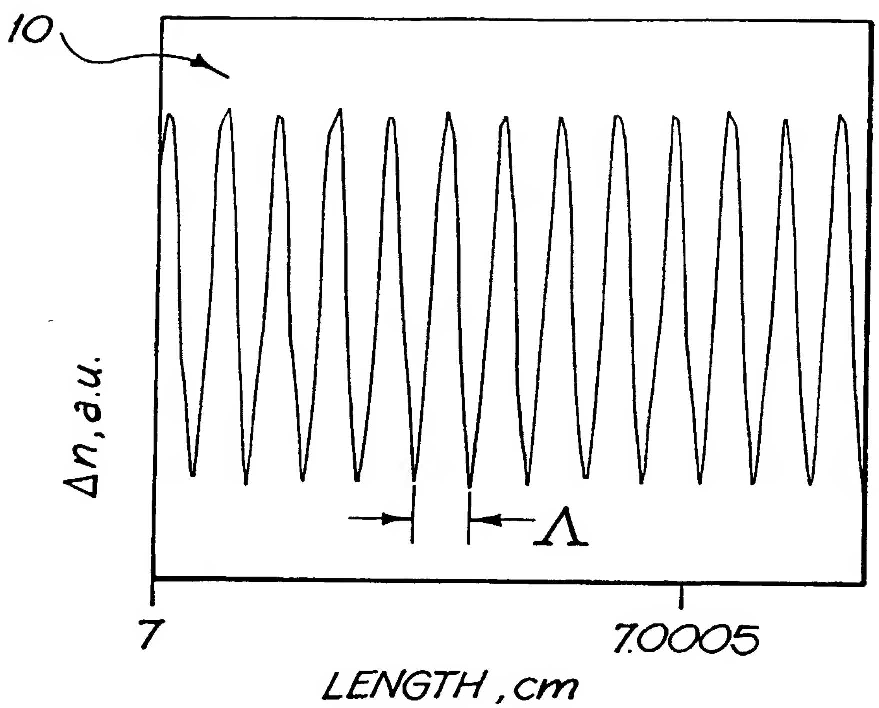


FIG. 1B

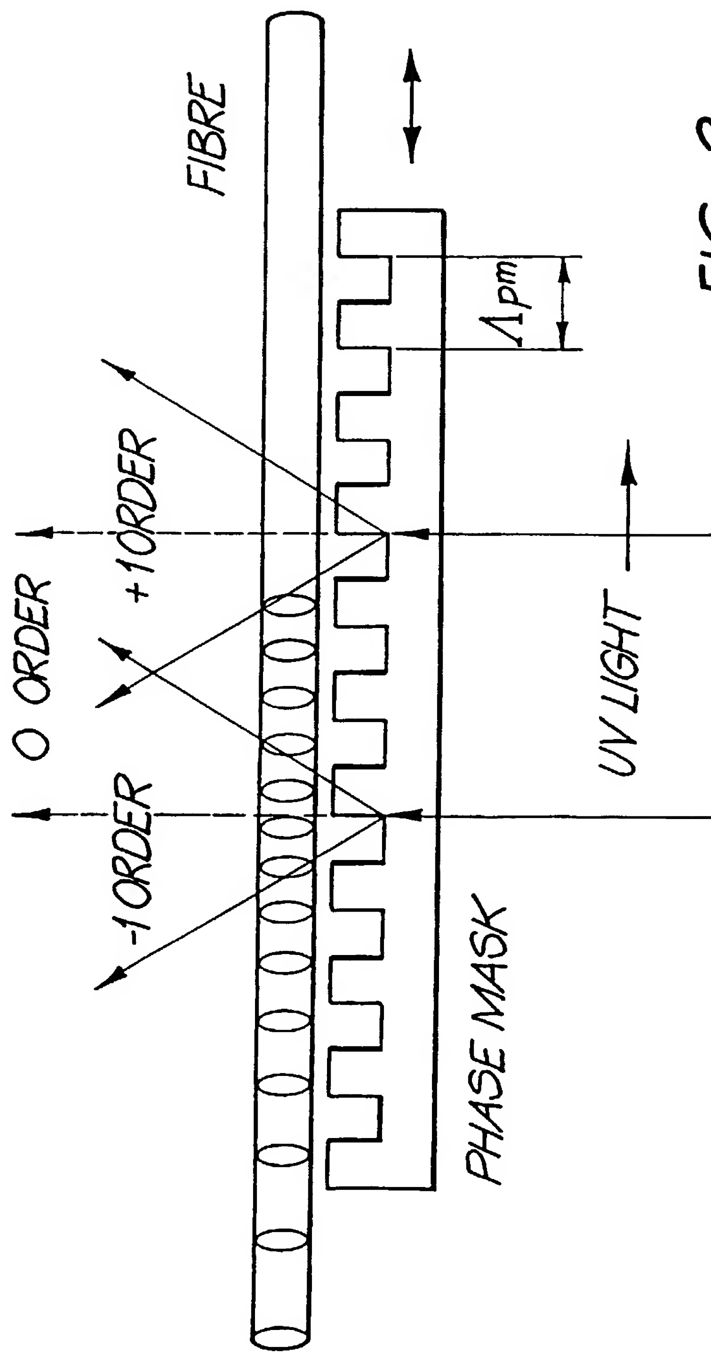
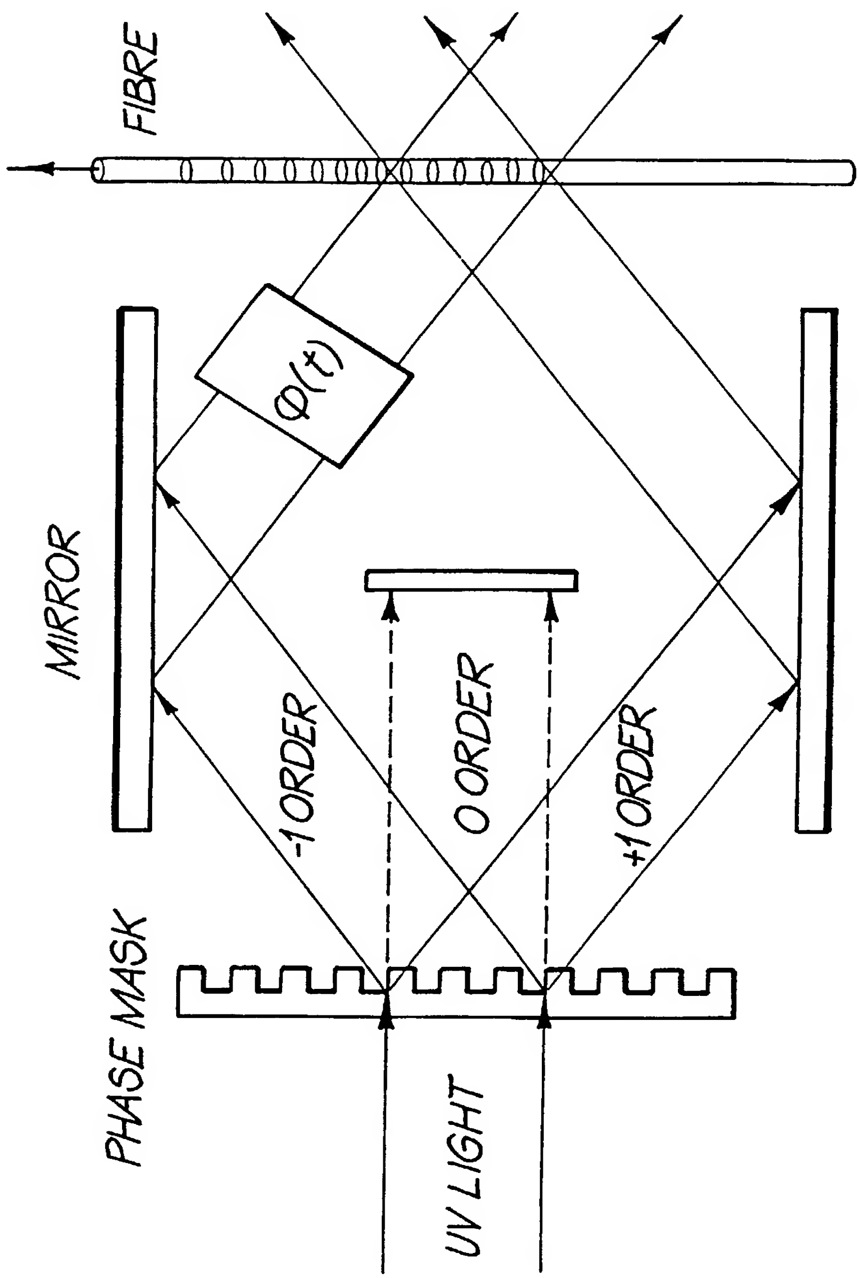


FIG. 2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MIRROR
$\varphi(t)$
PHASE MASK
UV LIGHT
-1 ORDER
0 ORDER
+1 ORDER

FIG. 3

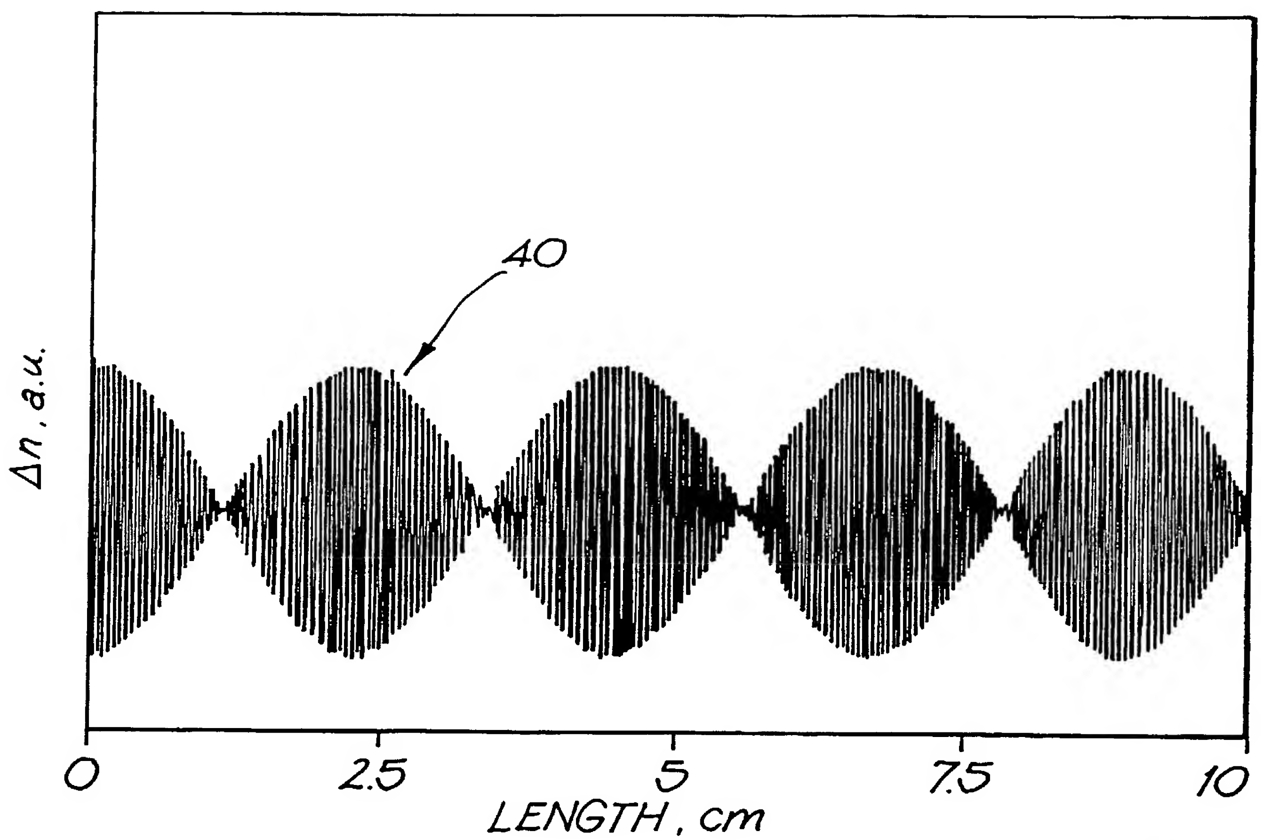


FIG. 4A

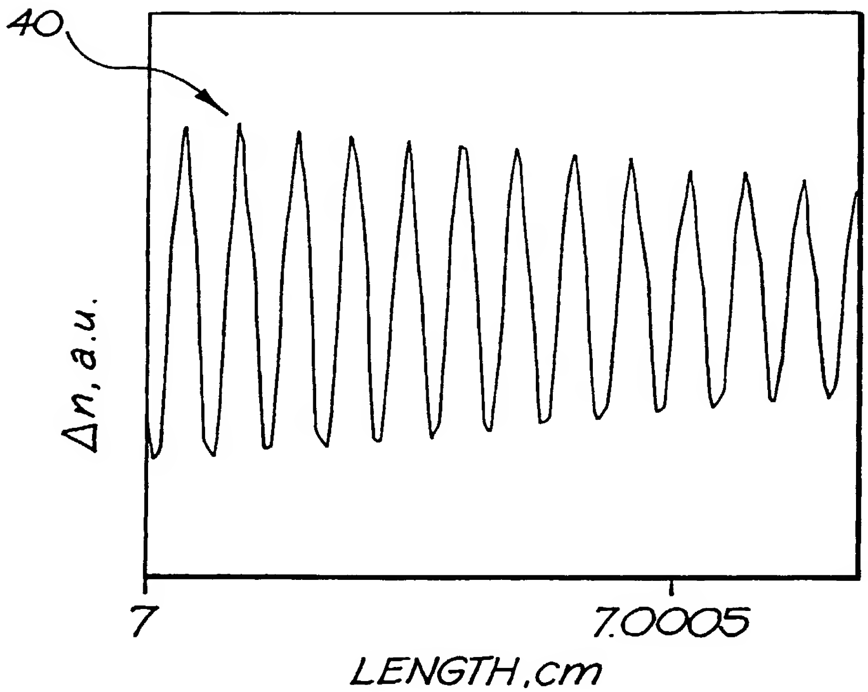


FIG. 4B

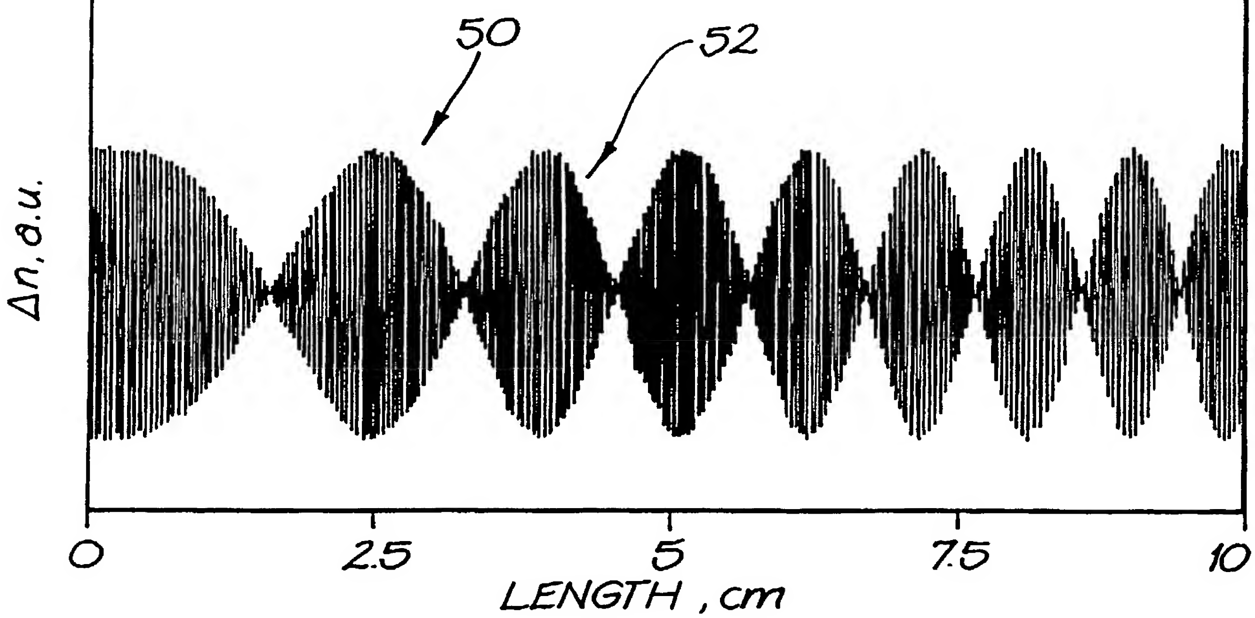


FIG. 5A

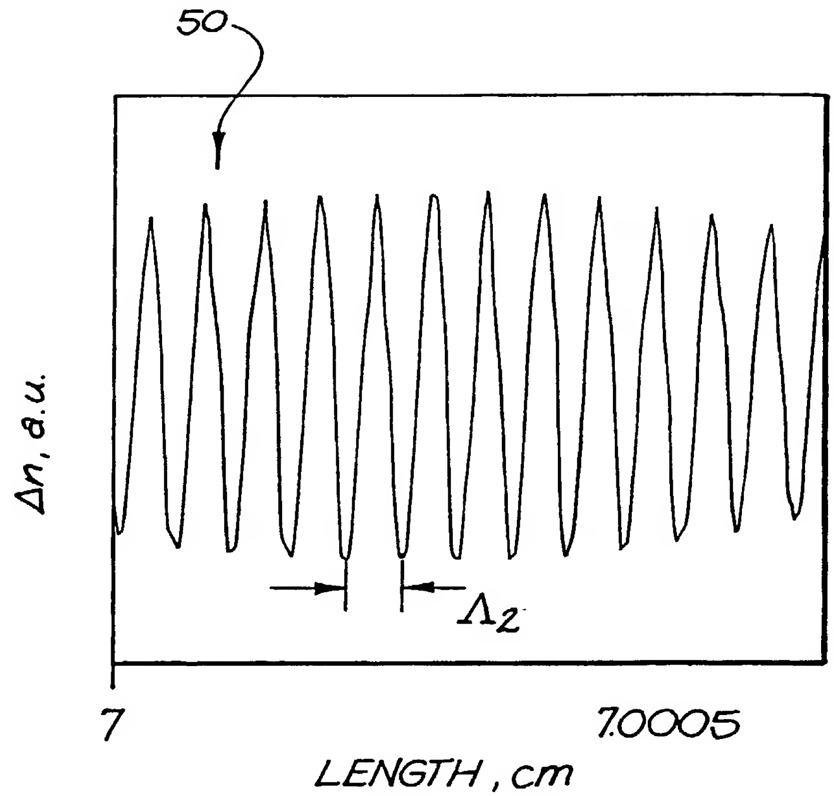


FIG. 5B

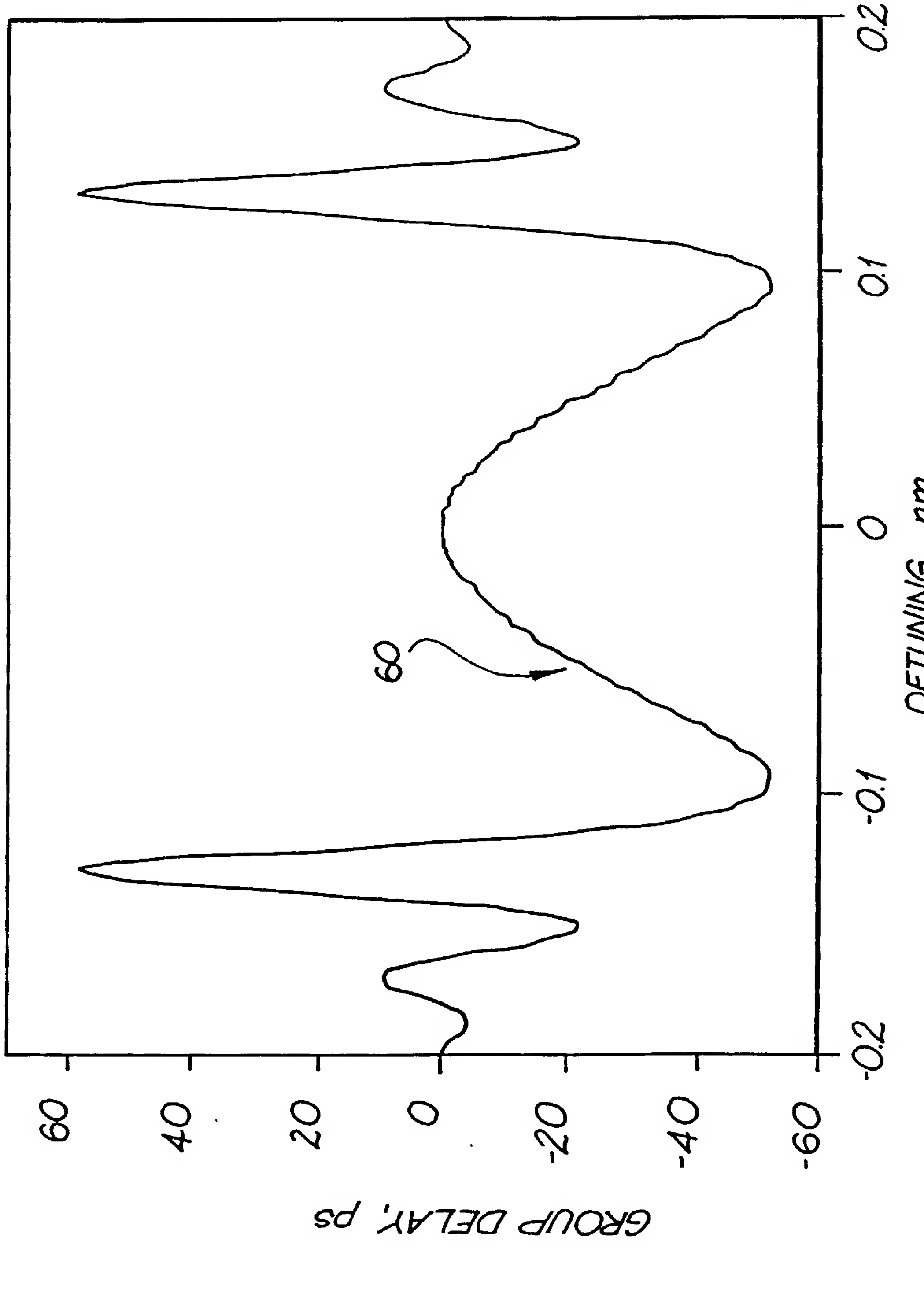


FIG. 6

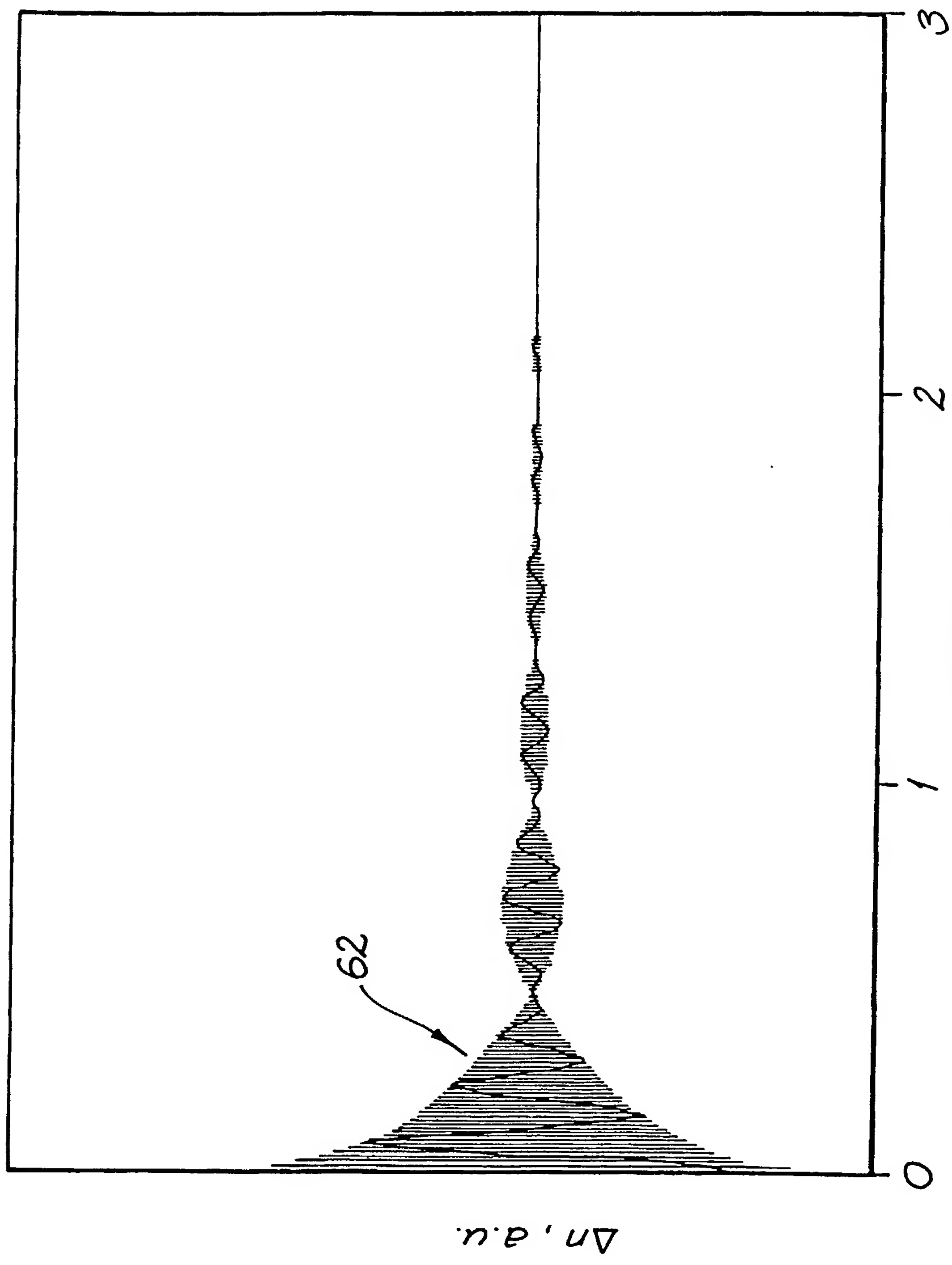


FIG. 7A

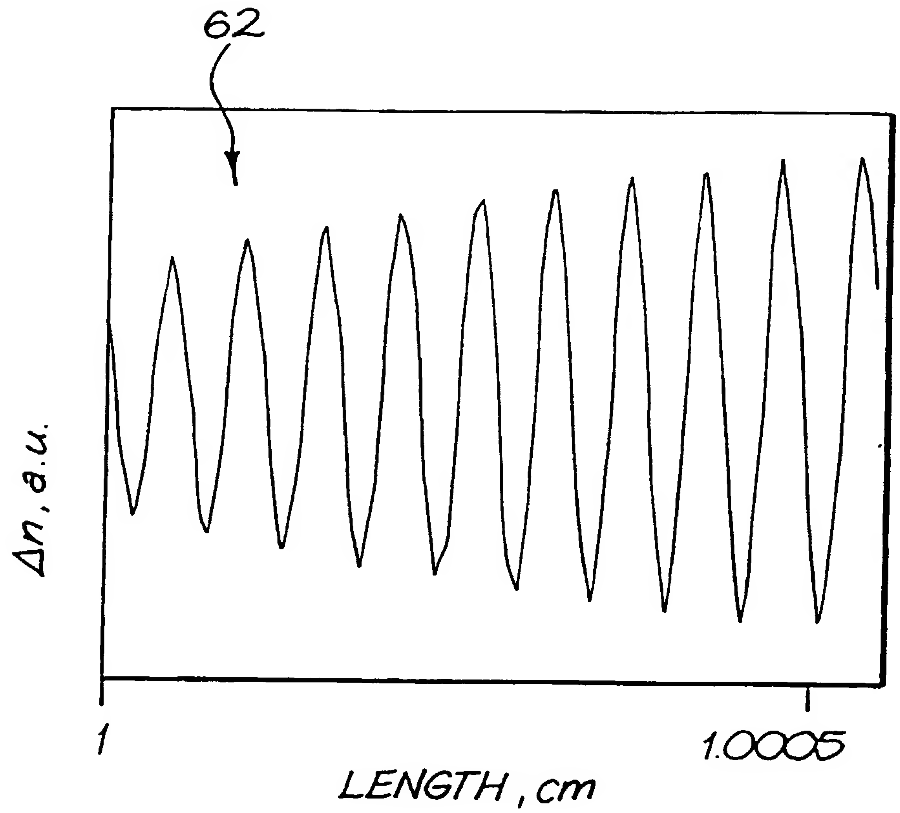


FIG. 7B

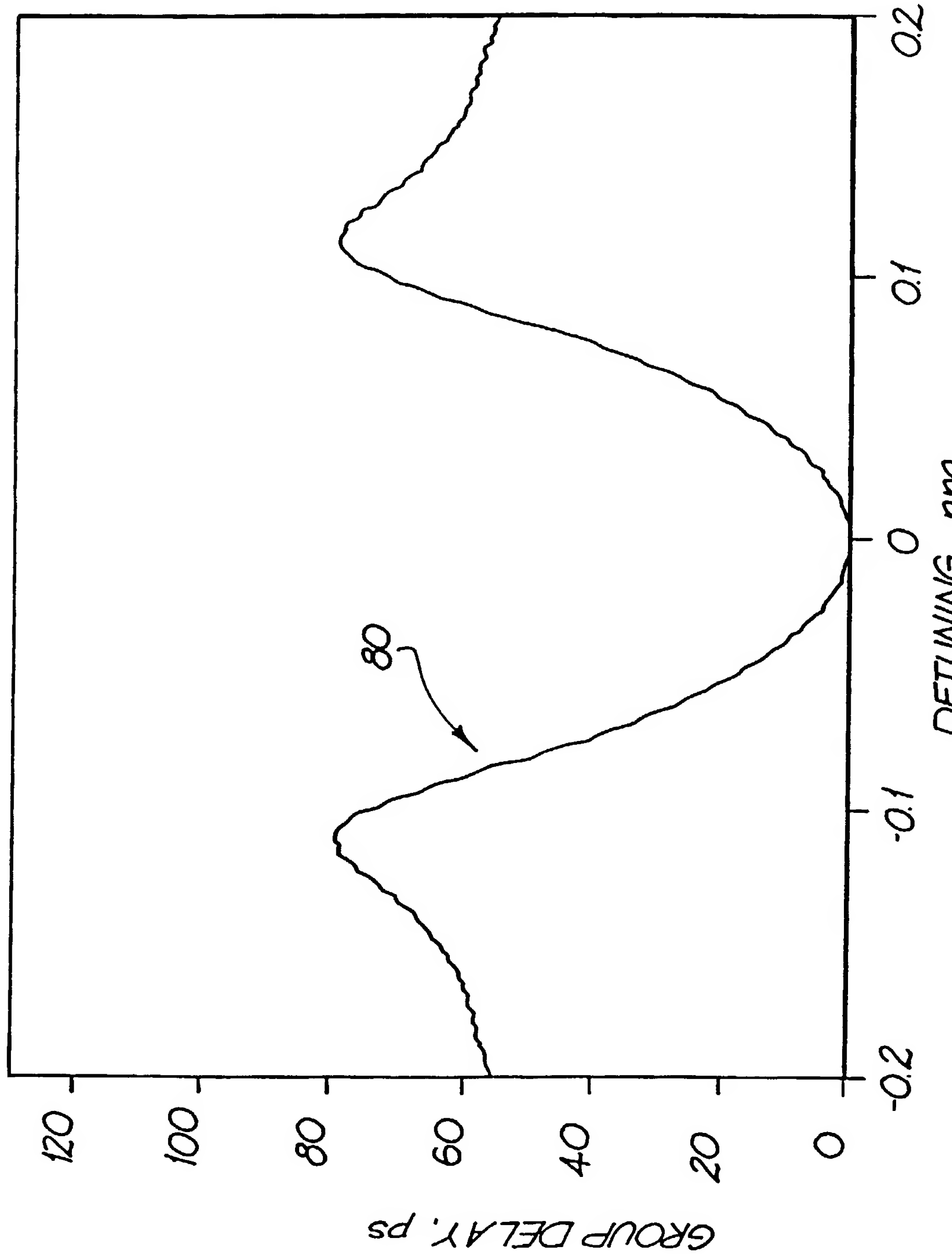
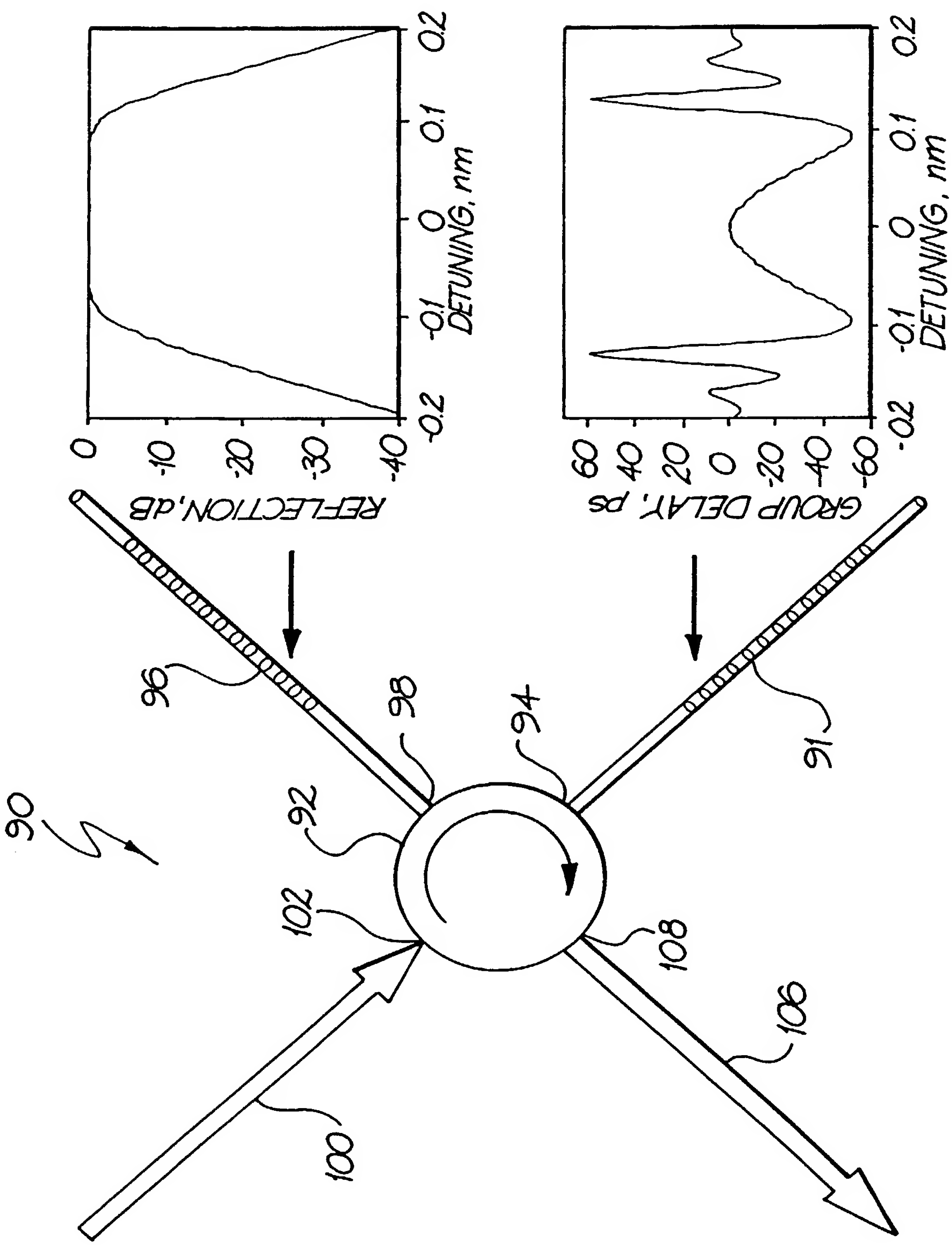
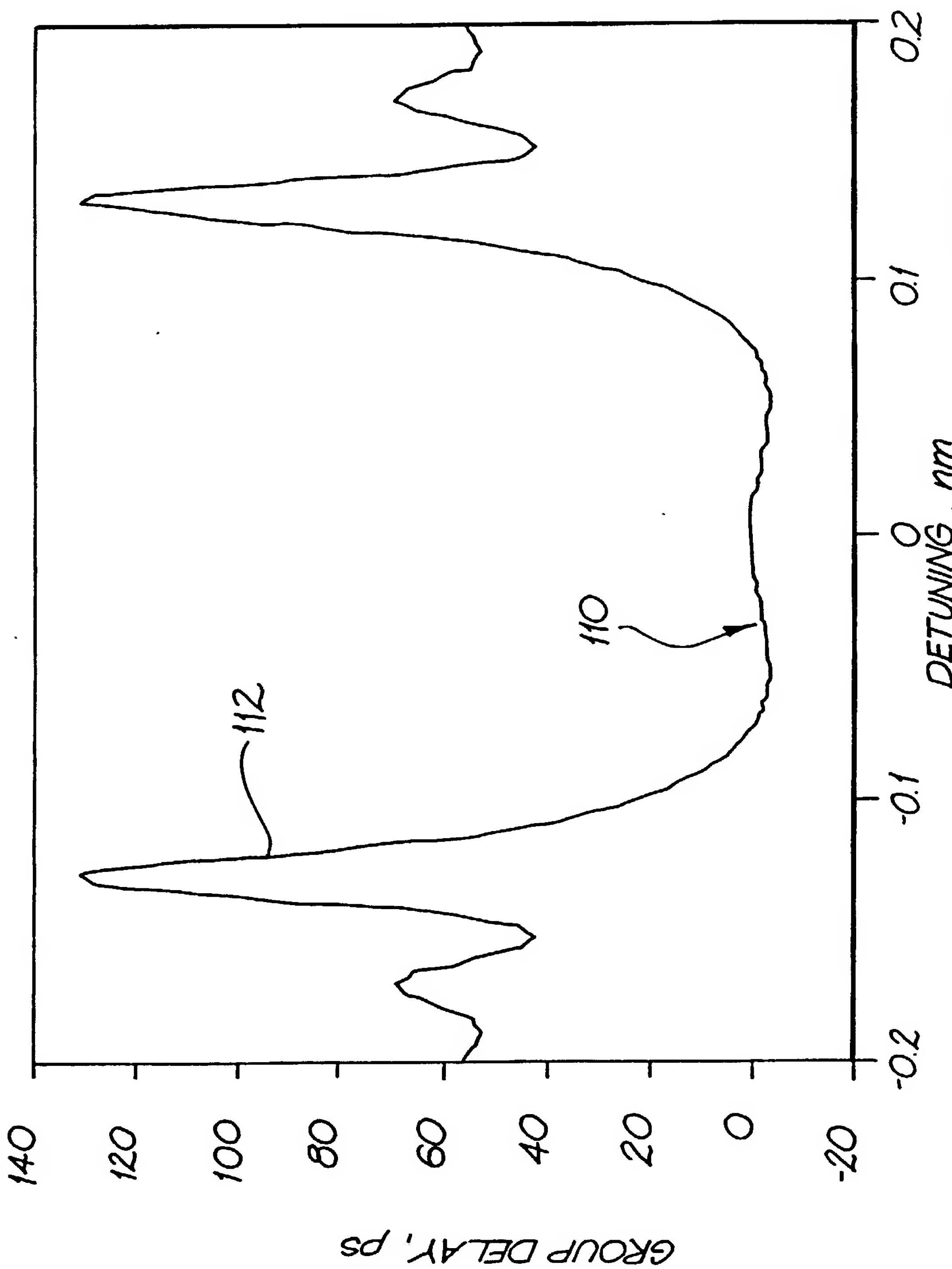


FIG. 8



REFLECTION, dB
0
-10
-20
-30
-40
-0.2
-0.1
0
0.1
0.2
DETUNING, nm
GROUP DELAY, ps
60
40
20
0
-20
-40
-60
-0.2
-0.1
0
0.1
0.2
DETUNING, nm
90
92
94
96
98
100
102
106
108
91

FIG. 9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120
100
80
60
40
20
0
-20
DETUNING, nm
-0.2
-0.1
0
0.1
0.2
112
110

FIG. 10

CRC 32-US

10088592.062702

DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled A GRATING DESIGN, the specification of which

☐ is attached hereto.

(check one)

☒ was filed on 21 September 2000 as
Application Serial No. PCT/AU00/01151
and was amended on N/A.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.
I acknowledge the duty to disclose to the Patent Office all information known to me to be material to patentability as defined in 37 C.F.R. 1.56.
I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) — Priority Claimed

(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
PQ3001/99	AUSTRALIA	21 September 1999	☒	☐
			☐	☐
			☐	☐

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose to the Patent Office all information known to me to be material to patentability as defined in 37 C.F.R. 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Title 18, United States Code, § 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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